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TITLE

## DEVICE FOR GONIOMETRIC MEASUREMENTS

Field of the invention

The present invention generally relates to a device for determining the angular position of an object.

5 In particular, the invention relates to a device for determining the relative angular position between two objects articulated to each other with at least one degree of freedom.

Furthermore, the invention relates in particular, but  
10 not exclusively, to a device for determining the relative angular position of two limbs of the human body, for example the arm and the shoulder, the forearm and the arm, the wrist and the elbow, etc.

Background of the invention

15 The angular movements between objects that have one or more degrees of freedom are measurable with complex devices of various structure of mechanical, optical, electromagnetic nature, etc.

One of the fields in which the angular measures are  
20 very important is that of the study of the posture of the human body by measure and control of absolute position data of single points of the body or of angular relative position of two adjacent limbs. On the basis of the data recorded a digital model of the human body is then  
25 created.

Many are the possible applications, such as the production of digital movies or virtual reality, as well

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as applications in the medical field, and deserve a space of primary importance in scientific research.

However some limits exist that define substantially the fields of applicability for each type of device. Such  
5 limits are given mainly to the size of the limb that has to be monitored and to the number of degrees of freedom of the limb same.

In particular, the limbs with greater volume, such as arms and legs, have less degrees of freedom and the  
10 devices used for detecting their motion have larger weight and encumbrance and require a higher rate of precision. The limbs with smaller volume, such as the fingers of the hands, have a higher number of degrees of freedom and the devices used for detecting their motion must have lower  
15 weight and encumbrance and require a lower rate of precision.

The least expensive devices for detecting the movement of the limbs with greater volume are of mechanical type. They provide the use of rigid parts connected with  
20 rotational and prismatic joints, measuring angular movements with potentiometers. Even if the costs of this technology are low, however the rigid structure has high encumbrance, it is heavy and the measures obtained are usually not so precise.

25. Also magnetic sensors exist; which require one or more transmitters for creating a magnetic field in a determined workspace. However, they have high costs and have the further drawback of being particularly affected by the presence of metal that can distort the magnetic field.

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The optical sensors, finally, require optical tracers, active or reflective, whose light is captured by cameras for then analysing the position data by means of a computer. Usually, the optical devices are less bulky of  
5 the magnetic, but their correct operation can be affected by parts of the body that cross accidentally the light path. Other drawbacks of the optical devices are high costs and the need for post-processing the measured data as well as the long set-up time for the measuring  
10 equipment.

Another system of "motion capture" for the human body is described in US6050962. It provides angular sensors of resistive type or "resistive bend sensors" arranged at the joints, associated to auxiliary articulated connections  
15 formed by a plurality of links hinged in turn. The links form a chain that can rotate in a single plane. Consecutive portions of chain can rotate in different planes connected to each other by stiff or articulated junction elements. The angular sensors are in particular  
20 resistive segments that measure the rotations of the limbs to which they are applied, or of portions of them. The resulting device is structurally complex and expensive.

#### Summary of the invention

It is therefore object of the present invention to  
25 provide a device for measuring the relative orientation of  
at least a first object with respect to a second object, in particular but not exclusively limbs of the human body, which is structurally easy and not expensive to make, and that does not present the drawbacks of the prior art.

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It is another object of the present invention to provide such a device that is light and has low encumbrance.

It is a further object of the present invention to  
5 provide such a device that is capable of measuring the angular rotation with sufficient precision.

These and other objectives are accomplished by the device for measuring the relative orientation of at least a first object with respect to a second object free from  
10 said first object, or connected to it but with independent movement, wherein said orientation is carried out according to at least one degree of freedom comprising:

- at least one goniometric sensor for said or each degree of freedom suitable for measuring the variation of  
15 orientation in a plane;
- at least one constraint generator for said or each goniometric sensor for causing the latter to move in said plane;

whose characteristic is that said or each constraint  
20 generator is an elongated flexible element, having a longitudinal axis, with a flexional stiffness remarkably lower in a first plane passing through the said axis and a flexional stiffness remarkably higher in a second plane orthogonal to said first plane and passing through the said  
25 axis, whereby said element is substantially flexible only in said first plane. Furthermore, said flexible element has also high stiffness to torsion and to elongation.

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In particular, the goniometric sensor measures the relative angular movement of the two objects in the bending plane of the constraint generator.

Advantageously, said or each goniometric sensor is  
5 located in a housing that crosses longitudinally said constraint generator.

Alternatively, the sensor is made in the flexible element same.

Advantageously, said or each constraint generator has  
10 a plurality of substantially parallel portions having larger cross section alternated to portions coaxial to the previous but with smaller cross section.

In a first embodiment, at the portions having smaller cross section flexible elements are arranged, or lamellar  
15 hinges, suitable for allowing the mutual rotation of said portions having larger cross section only in the bending plane of the constraint generator.

Alternatively, said or each constraint generator is a plate shaped element from which projections extend  
20 substantially bellow-like. In particular, said bellow-like projections have structure chosen among: helical; alternated annular portions having larger and smaller cross section.

Preferably, the constraint generator has flanges at its ends orthogonal to said axis for connecting more  
25 constraint generators in series or for connecting to the objects whose rotation must be detected.

Preferably, the goniometric sensor for measuring the relative rotation of the ends of said constraint generator comprises:

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- a flexible elongated element that extends between said ends, said element having a neutral axis which does not change its own length when bending, and at least one fibre spaced apart from said neutral axis and that extends from said first to said second object;
- means for measuring the length variation of said fibre as the relative rotation varies between said first and said second object, said relative rotation being proportional to said length variation.

10 According to a particular aspect of the invention, when said first object can rotate about more axes with respect to said second object, the use is provided of a plurality of constraint generators connected rigidly in series at the respective ends and in particular a  
15 constraint generator for each axis of rotation, or rotational degree of freedom, and oriented according to different planes of flexion, so that each sensor present in the corresponding constraint generator measures the bending in a different plane. In this case the relative rotational  
20 movement of the first object with respect to the second object is computed combining the measures of angular movements in each flexion plane.

This solution can be used, for example, if the movement has to be measured of the shoulder of an individual  
25 with respect to another point of the body. In this case, considering the rotational constraint of the arm with respect to the shoulder as a ball joint, a device can be used for measuring the rotation of the arm with respect to the shoulder comprising in series three constraint

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generators integrated to three goniometric sensors according to the invention. The first has a free end integral to the shoulder and is oriented for bending in a first plane, the second in a second plane orthogonal to the first and the  
5 third in a third plane orthogonal to the second with its free end integral to the arm.

Moreover, a device for measuring the rotation of the forearm with respect to the arm comprises a constraint generator and a relative goniometric sensor, with an end  
10 integral to the arm and the other end integral to the forearm.

A particular aspect of the invention relates to a device for measuring the rotation of the wrist of an arm comprising at least one goniometric sensor as above  
15 described. In particular, said or each goniometric sensor is arranged with an end integral to the wrist and with the other end constrained to a second point of the arm that during the rotation of the wrist remains substantially fixed, for example to the elbow. Therefore, the  
20 goniometric sensor measures the rotation of the wrist with respect to the second point of the arm.

According to another particular aspect of the invention, a data suit for measuring the angular rotation of the arm with respect to the shoulder, of the forearm and  
25 of the wrist with respect to the arm of an individual comprises:

- a device for measuring the rotation of the arm with respect to the shoulder as above described;

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- a device for measuring the rotation of the forearm with respect to the arm, as above described, arranged orthogonally to said device for measuring the rotation of the arm with respect to the shoulder;

- 5       - a device for measuring the rotation of the wrist, as above described, having an end rigidly connected to said device for measuring the rotation of the forearm with respect to the arm.

Brief description of the drawings

10       Further characteristics and the advantages of the device according to the present invention will be made clearer with the following description of an embodiment, exemplifying but not limitative, with reference to the attached drawings, wherein:

- 15       - figure 1 shows a top plan view of a constraint generator according to the invention;
- figure 2 shows a longitudinal sectional view according to arrows II-II of the constraint generator of figure 1;
- figure 3 shows an elevational side view of the
- 20       constraint generator of figure 1;
- figure 4 shows an elevational front view of the constraint generator of figure 1;
- figure 5 shows a perspective view of the constraint generator of figure 1;
- 25       - figure 6 shows a perspective view of a different embodiment of the constraint generator of figure 1;
- figure 7 shows a top plan view of the constraint generator of figure 6;
- figure 8 shows a longitudinal sectional view according



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to arrows VIII-VIII of figure 7 of the constraint generator of figure 6;

- figure 9 shows a longitudinal sectional view according to arrows IX-IX of figure 8 of the constraint generator of  
5 figure 6;

- figure 10 shows a top plan view of a not helical embodiment of the constraint generator of figure 6;

- figure 11 shows a top plan view of three constraint generators rigidly connected and oriented on orthogonal  
10 bending planes, so that each sensor present in the relative constraint generator measures the bending occurring in the corresponding plane;

- figure 12 shows a top plan view of a device for measuring the angular rotation of the wrist and of the  
15 forearm with respect to the arm, according to the invention;

- figures 13 and 14 show respectively in a perspective view and a top plan view a data suit for measuring the angular rotation of the arm with respect to the shoulder, of the forearm and of the wrist with respect to the arm of  
20 an individual, according to the invention;

- figure 15 shows a longitudinal sectional view of a possible embodiment of a goniometric sensor suitable for being arranged in the constraint generator of figure 1 or of figure 6;

25 - figure 16 shows diagrammatically in a perspective elevational side view the data suit of figure 12 that an individual has put on;

- figures from 17 to 19 show a perspective view of a possible embodiment of a device for measuring the rotation

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of the wrist, according to the invention.

Description of a preferred embodiment

In figures from 1 to 5 a device 1 is shown, according to the invention, for measuring the relative orientation according to at least one degree of freedom of two separated objects, or connected objects but having independent movement. It comprises a constraint generator 10 suitable for causing a goniometric sensor 40 to move in a plane for measuring the variation of relative orientation of the two objects in that plane.

As shown in the cross sectional view of figure 2, goniometric sensor 40 is arranged in a housing 41 that crosses longitudinally constraint generator 10. A type of goniometric sensor is shown in figure 15, and described hereinafter.

With reference to figure 5, constraint generator 10 has a longitudinal axis 8 and is equipped with a high flexional stiffness when bending in a first plane  $\beta$  passing through that axis 8 and a low flexional stiffness when bending in a second plane  $\phi$  orthogonal to plane  $\beta$  and passing through axis 8 same. Therefore, constraint generator 10 is flexible only in plane  $\phi$  and goniometric sensor 40 measures the relative angular movement of the two objects in this plane.

Always with reference to figure 1, constraint generator 10 has a plurality of substantially parallel portions having larger cross section 2 alternated to a plurality of portions coaxial to the previous having smaller cross section 3. In particular, the portions having smaller

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cross section 3 allow bending and cause the mutual rotation of the portions having larger cross section 2 only in bending plane  $\phi$  of constraint generator 10. In particular, narrower zones 3 are made as lamellar hinges that extend in  
5 or parallel to plane  $\beta$ , and then allow bending only in plane  $\phi$ . At the ends fastening flanges 5a and 5b are provided, for either connecting the constraint generators 1 in series according to orthogonal planes, or connecting the constraint generators to the objects whose rotation must be detected.

10 In an alternative embodiment of the invention and shown in figures from 6 to 10, constraint generator 10 can comprise a plate-shaped portion 6, with larger dimensions parallel to plane  $\beta$  and lower dimension in plane  $\phi$ . From plate-shaped portion 6 substantially bellow like  
15 projections 2 extend that are arranged helically in axial direction. At the end of plate 6 fastening flanges 5a and 5b orthogonal to plate 6 same can be, furthermore, provided.

Alternatively, as shown in figure 10, the bellow-like  
20 shape is obtained by a plurality of rings alternated of diameter higher 2 and lower 3 that project from plate 6.

In both cases, plate-shaped portion 6 has flexional stiffness remarkably higher in plane  $\beta$ , and can bend in plane  $\phi$  to it orthogonal. Furthermore, the bellow like  
25 structure increases the torsional stiffness.

The constraint generator according to the invention in the various embodiments, and made in other equivalent ways, can be manufactured directly by moulding in a single element of plastics.

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In figure 15 in a longitudinal sectional view a possible embodiment of goniometric sensor 40 is shown. On sensor 40 a neutral axis 100 in case of bending does not change its own length, and with numeral 105 a line is indicated eccentric to the neutral axis. When the two objects of whose relative orientation has to be determined rotate reciprocally, then flexible elongated element 42 is subject to a bending that produces a length variation of the fibres not located at neutral axis 100. In particular, the fibre located at eccentric line 105 is subject to a length variation  $\Delta L$ . This length variation of fibre 105 can be determined by means of a sensor 47, for example a Hall effect sensor, which detects the movement of a cable 45 located in a channel 44 made in the element end 42. In particular, sensor 47 measures the movement of a magnet 46 connected to an end of cable 45 and sliding in an enlarged portion 44a of channel 44.

The goniometric sensor can be inserted after the moulding of the constraint generator or embedded in the plastic matrix of the constraint generator. In a further embodiment, the goniometric sensor is made directly in constraint generator 10, carrying out a measure of lengthening of a fibre different from the neutral axis of constraint generator 10 same, in a way similar to the goniometric sensor shown above.

The type of goniometric sensor used, obviously, is exemplifying and not limitative, and goniometric sensors of other type can be used capable of measuring the rotation of the two ends of constraint generator 10.

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According to a particular aspect of the invention, if the orientation has to be measured of a first object capable of rotating about three axes with respect to a second object, the use is provided of three constraint generators 5 10 connected rigidly in series at the ends 5 (figure 11). In particular, the three constraint generators 10 are oriented according to the different bending planes, so that each sensor 40 present in the corresponding constraint generator 10 measures the bending in a different plane. Therefore, the 10 relative rotational movement of the first object with respect to the second object is computed, in this case, combining the measures of angular movements in each flexion plane.

This solution can be, for example, used for measuring 15 the movement of arm 76 of an individual with respect to the shoulder (figure 16). In this case, considering the movement of the arm with respect to the shoulder 75 as a spherical movement characterised by 3 independent degrees of freedom, such rotations are measurable with device 50 for measuring 20 the rotation of arm 76 with respect to shoulder 75, comprising the three constraint generators 10 in series and the relative three goniometric sensors 40 to it associated.

Always with reference to figure 16, first constraint generator 10a has a free end 5a integral to shoulder 75 and 25 is oriented for bending in a first plane. Second constraint generator 10b has end 5a rigidly connected to end 5b of first generator 10a and is oriented for bending in a second plane orthogonal to the first flexion plane. Third constraint generator 10c has in turn an end 5a rigidly

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connected to end 5b of second generator 10b, it is oriented for bending in a third plane orthogonal to the second bending plane and has the free end 5b connected to a support 80 integral to arm 76 by means of a belt 81.

5 Similarly, a device 20 for measuring the rotation of forearm 77 with respect to arm 76 comprises a constraint generator 10 and a relative goniometric sensor 40. In this case, a first end 5a of constraint generator 10 is mounted on a support 80 integral to arm 76 by means of a belt 81  
10 and the other end 5b is fixed to a support 82 integral to forearm 77 by means of a belt 83 (figure 16). Finally, if at end 5b of device 20 a rod 31 is connected, as detailed in figures from 17 to 19, having a free end at the wrist 65 and provided with a goniometric sensor 40 (with or  
15 without constraint generator), it is possible to measure also the rotation of the wrist 65 with respect to arm 76.

Notwithstanding reference has been made mainly to the movement of an arm with respect to a shoulder, a forearm and a wrist, the above mentioned device can be easily  
20 implemented by a skilled person for measuring the motion of other parts of the body such as legs, head, trunk, etc.

The foregoing description of a specific embodiment will so fully reveal the invention according to the conceptual point of view, so that others, by applying current  
25 knowledge, will be able to modify and/or adapt for various applications such an embodiment without further research and without departing from the invention, and it is therefore to be understood that such adaptations and modifications will have to be considered as equivalent to the specific

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embodiment. The means and the materials to realise the different functions described herein could have a different nature without, for this reason, departing from the field of the invention. It is to be understood that the phraseology  
5 or terminology employed herein is for the purpose of description and not of limitation.